PARTICULATE CONTAMINATION CONTROL FOR THE VIKING AND VOYAGER UNMANNED PLANETARY SPACECRAFT

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ABSTRACT

Particles released during the flight of planetary spacecraft can result in either unacceptable performance of science instruments or in mission operations problems caused by particles interfering with the celestial sensors. Because of planetary protection requirements for spacecraft flying to planets of biological interest, a high degree of exterior particulate cleanliness is also desirable to reduce the likelihood of the accumulation of microbial burden on spacecraft surfaces. To minimize the accumulation of particulate matter on the spacecraft exterior surfaces, the Viking and Voyager projects contamination control programs consisted of establishing cleanliness requirements for facilities, equipment, and personnel. This paper discusses the effectiveness of these programs during the prelaunch operations at Cape Canaveral.

The final assembly and checkout of the Viking and Voyager unmanned planetary spacecraft occurred in Class 100,000 (or better) cleanrooms. Following spacecraft encapsulation, the payload was continuously subjected to Class 100 air during transport, hoist, and on-pad operations. Several different particulate determination approaches were used to verify not only spacecraft surface cleanliness but also air cleanliness. These included visual inspection of surfaces with and without magnifying aids, collection of visible surface particles for chemical analysis, light scattering particle measuring devices, and specially developed samples for monitoring exhaust air.

Visual inspections of spacecraft surfaces occurred periodically during the prelaunch operations. The contamination control inspection team would either certify cleanliness of the spacecraft or require additional cleaning. When it was necessary to identify the types of particles noted, particles were subject to chemical or spectral analyses.

Volumetric measurements of the air cleanliness of the cleanrooms and the encapsulated payload air conditioning systems were made using light scattering instruments. The data shows that the air cleanliness requirements for the cleanrooms and the air conditioning systems were satisfied. To obtain reliable measurements at high air velocities, as in the air conditioning ducts, specially designed isokinetic probes were used.

To evaluate air cleanliness during the transport and hoist operations of the encapsulated spacecraft, a pair of specially designed 45 mm disc samples were placed in the exhaust area of the payload. This technique proved acceptable for obtaining qualitative type of measurements during the five air conditioning changes during these operations as well as during on-pad operations if inlet air cleanliness became marginal.

Finally, in-flight bright particle occurrences as detected by the star trackers are used as an indirect indication of surface cleanliness. Based on comparisons with previous Mariner spacecraft, the Viking and Voyager spacecraft have had fewer bright particle occurrences.

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1.0 INTRODUCTION

Two Viking and two Voyager unmanned planetary spacecraft were successfully launched from Cape Canaveral in 1975 and 1977, respectively. All of these spacecraft were prepared for launch in compliance with particulate contamination control programs that had evolved primarily from earlier unmanned projects (reference 1). However, there were significant differences for the Viking and Voyager programs. These included new facilities, different planetary protection constraints, and new on-pad particulate monitoring approaches. This paper discusses the Viking and Voyager particulate contamination control programs at Cape Canaveral including the hardware flow through the various facilities, the monitoring methods employed, the results obtained, and the in-flight experience.

For the Viking and Voyager spacecraft there were three reasons for implementing a particulate contamination control program; 1) minimize the likelihood of encountering particles in the field of view of optical guidance equipment, i.e., celestial sensors, 2) minimize particle liklihood in or on optics of scientific experiments, 3) enhance the chances of satisfying the spacecraft planetary protection constraints for the launch preparation activities.

There was a difference between the two programs in the importance of these reasons. For Viking, planetary protection was the dominant reason. For Voyager, optical guidance equipment and science instruments were dominant.

Three methods were used for controlling particulate contamination during spacecraft prelaunch preparation: facilities, personnel constraints, and special hardware protective measures such as dry nitrogen purging or equipment dust covers.

2.0 FACILITY AND PERSONNEL REQUIREMENTS

The facilities used for Viking and Voyager prelaunch preparation were similar, although there were modifications and changes to the payload transporter, and on-pad air conditioning system between the two programs. Table 1 summarizes the facility capabilities; and indicates their specific utilization during the Viking and Voyager programs for major payload items. Several points regarding these facilities should be emphasized. The air cleanliness level was a class 100,000 or better.* After payload encapsulation, the air cleanliness was class 100 or better to the time of launch. The encapsulated payload experienced five air conditioning changes from the time of encapsulation in the assembly facility to the time of installation on top of the launch vehicle at Launch Complex 41.

Personnel constraints imposed on the spacecraft test team included garment requirements and limited access to the facilities. The garment requirements are summarized in Table 2 and shown in Figure 1. Significant complaints noted by the team regarding the garments were 1) hoods restricted peripheral vision and 2) bunny suits and hoods caused discomfort, i.e., too warm, if worn continuously for long periods of time.

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* Per Federal Standard 209b, Federal Standard Cleanroom and Work Station Requirements Controlled Environments, 1972

Payload Item	Hangar AE	Hangar AO	ESA 60A	SAEF 1 & 2	Transporter	Launch Complex 41
Facility Environments	Class 300,000 Air $\sim 21^{\circ}C$ $\sim 45\%$	Class 10,000 Air $21 {}^{+3}_{-0}{}^{\circ}C$ $45 \pm 5\%$	Class 100,000 Air $21 {}^{+3}_{-0}{}^{\circ}C$ $45 \pm 5\%$	Class 100,000 Air $21 {}^{+3}_{-0}{}^{\circ}C$ $45 \pm 5\%$	Class 100 Air	Class 100 Air
VIKING						
Orbiter		X	X	X		
Lander				X		
Shroud	X			X		
Encap. Payload[(a)]				X	X	X
VOYAGER[(b)]						
Mission Module		X		X		
Propulsion Module			X	X		
Shroud	X					
Encap. Payload				X	X	X

a) Includes orbiter, lander and shroud in encapsulated configuration.

b) Includes mission module, propulsion module, shroud in encapsulated configuration.

Table 1 - Cape Canaveral Facilities Utilized by Viking and Voyager Payload Items

TABLE 2 - CLEANROOM GARMENT REQUIREMENTS FOR VIKING AND VOYAGER CAPE CANAVERAL OPERATIONS

	SAEF 1&2	ESA 60	HANGAR AO
HEAD	Fullhood, Tyvek Disposable (Moustache Covers)*	Fullhood, Tyvek Disposable (Moustache Covers)*	Fullhood, Tyvek Disposable (Moustache Covers)*
BODY	Bunny Suits, Nomex for all S/C and S/C/ transporter operations in designated area Bunny Suits, Dacron elsewhere in high bay	Bunny Suits, Nomex or if Nomex unavailable, Smock and Pants, Nomex	Bunny Suits, Tyvek Disposable
HANDS**	Gloves, ** --Nylon	Gloves, ** Nylon	Gloves, ** Nylon
FEET	Approved Cleanroom Shoes or Booties, Tyvek Disposable	Approved Cleanroom Shoes or Booties, Tyvek Disposable	Approved Cleanroom Shoes or Booties, Tyvek Disposable

*Required for personnel with moustaches.
**Gloves are required whenever flight equipment is handled except when an operation is so delicate that gloves impede the operation.

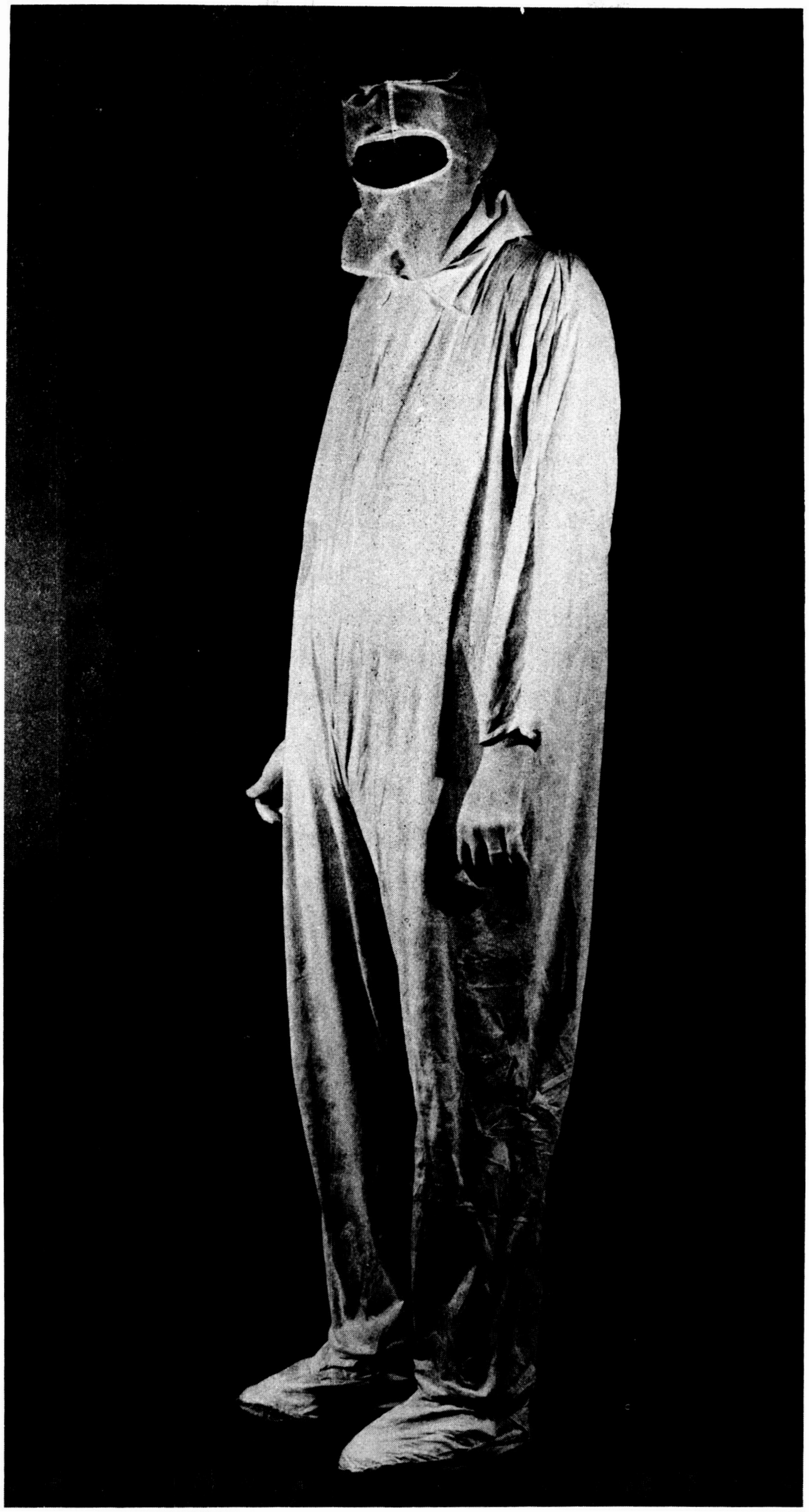

Figure 1 Example of Personnel Clothing Requirements

3.0 MONITORING METHODS

Several qualitative and quantitative particulate monitoring methods were applied during the Viking and Voyager programs. The qualitative methods included visual inspections of spacecraft surfaces with and without magnifying aids and collection of particles for chemical or physical analysis. The quantitative methods were based on the utilization of light scattering monitors for enumerating the number of dust particles in a given volume of air.

3.1 Visual Inspection

The spacecraft prelaunch visual inspections were performed by an inspection team consisting of quality assurance and contamination control personnel while work platforms were in positions favorable for viewing spacecraft surfaces. The inspection team would walk slowly around the spacecraft at each level looking for dirt particles. Magnifying aids (10X magnifying glasses) were occassionally used. Special attention was paid to cracks and crevices where dust particles could have been overlooked during earlier cleaning operations. The team would either certify cleanliness of the spacecraft or require additional cleaning. The principal visual inspection occurred just before the spacecraft was encapsulated in the protective shroud. The basic requirement that had to be satisifed was that the spacecraft surfaces had to be visually clean. When it was necessary to identify the types of particles visually observed on the surfaces, particles were removed by "picking them" with a lint free cloth, adhesive tape, or a cotton swab and placing the particle in a suitable container such as a clean petri dish. The particles were then taken to the chemical and spectral facility for analysis.

3.2 Facility Monitoring

To assure that the specified requirement "visually clean" was satisfied and that the spacecraft were not subsequently subjected to dirty air, a facility monitoring program was implemented. This program consisted of performing periodic measurements in the high bay areas of the clean room immediately before and during spacecraft operations using light scattering monitors, verifying air cleanliness of inlet air for the encapsulated payload using light scattering monitors with isokinetic probes, and monitoring the payload exhaust air using light scattering monitors and "disc" samples. A description of each of these methods is given in the following. Their utilization is summarized in Table 3.

3.2.1 Volumetric Light Scattering Monitor

The volumetric light scattering monitor pulls air into the instrument where a bright beam of light is projected through the airstream and detects the presence of particles by sensing the light scattered by the particles. Each particle passing through the viewing field generates a light pulse which is detected by a photomultiplier tube. Since the amount of light reaching the photomultiplier tube varies with the size of the particles, the output pulses from the tube can be used to count particles and to classify them according to size. The normally used size ranges, $\leq 0.5\mu$ and $\geq 5.0\mu$, were applied for the Viking and Voyager particle monitoring efforts and measurements were reported as the number of particles per cubic foot of sampled air.

In the high bay areas with daily activity, such as the SAEF's and Hanger AO, continuous measurements were taken using automatic light scattering monitors. The resulting strip charts were read by facility personnel to verify compliance of the clean room with air cleanliness requirements.

TABLE 3 - PARTICULATE MEASUREMENT REQUIREMENTS FOR VIKING AND VOYAGER CAPE CANAVERAL OPERATIONS.

Monitoring Method	Pre Encapsulation					Post Encap.		Transport				Launch Complex 41			
	Hanger AO	ESA 60 (c)	SAEF 1 or 2	SAEF Payload Air		SAEF Payload Air		SAEF Airlock Air		Transporter Air		Hoist Air		Payload Air	
				Inlet	Nozzle Outlet	Inl	Exh	Inl	Exh	Inl	Exh	Inl	Exh	Inh	Exh
Particle Counter															
Std. particle counter aperature (high bay areas)															
• Continuous	X	X	X												
• Periodic (a)	X	X	X												
Isokinetic probe(s)															
(Ducted air to payload)															
• CSS airborne ducting cleanliness verification				X (f)	X (g)										
• Premate Survey (d)						X		X		X		X		X	
• Continuous														X	
• Periodic							X		X						X (e)
Disc Samples							X (b)		X		X		X		X (b)

(a) In close proximity to spacecraft.

(b) As required, see acceptance criteria.

(c) Requirements if ESA60 used for Ops.

(d) Premate survey of air conditioning system prior to connecting air to encapsulated payload.

(e) Once every 12 hrs. for a minimum of 30 minutes.

(f) Premate survey.

(g) After several hours of blowdown.

Light scattering monitors were used to periodically measure the number of particles in the air near the spacecraft during assembly and test operations. This data was also used to verify compliance of the clean room with air cleanliness requirements.

In conjunction with the isokinetic probes the light scattering monitors were used for premate surveys to verify air quality of air conditioning systems prior to connecting air to shroud or encapsulated payload and for periodic sampling of the inlet and exhaust air on the launch pad.

3.2.2 Isokinetic Probes

Because of the possibility of obtaining erroneous readings from the light scattering monitors while sampling air in an air conditioning duct (or exhaust port) moving at high flow velocities, specially designed isokinetic probes were required on the end of the inlet tube to the instrument. Figure 2 was used to select the proper probe inlet size. The methodology consisted of the following steps. First to measure the flow velocity at the location to be sampled using a manometer or a hot wire anemometer, and second to enter Figure 2 and select the probe nearest to the measured velocity always using the largest probe inlet size closest to the measured velocity. If velocities exceeded 20m/s, the higher (1m/s) sampling flow rate was used.

3.2.3 Disc Samples

For several post encapsulation operations, such as transport and hoist, particle measurements using light scattering monitors were impractical. To provide particles for performing qualitative assessments, special devices, called disc samples, were designed. The purpose of the samples was to provide a mechanism for trapping particles entrained in the payload exhaust air.

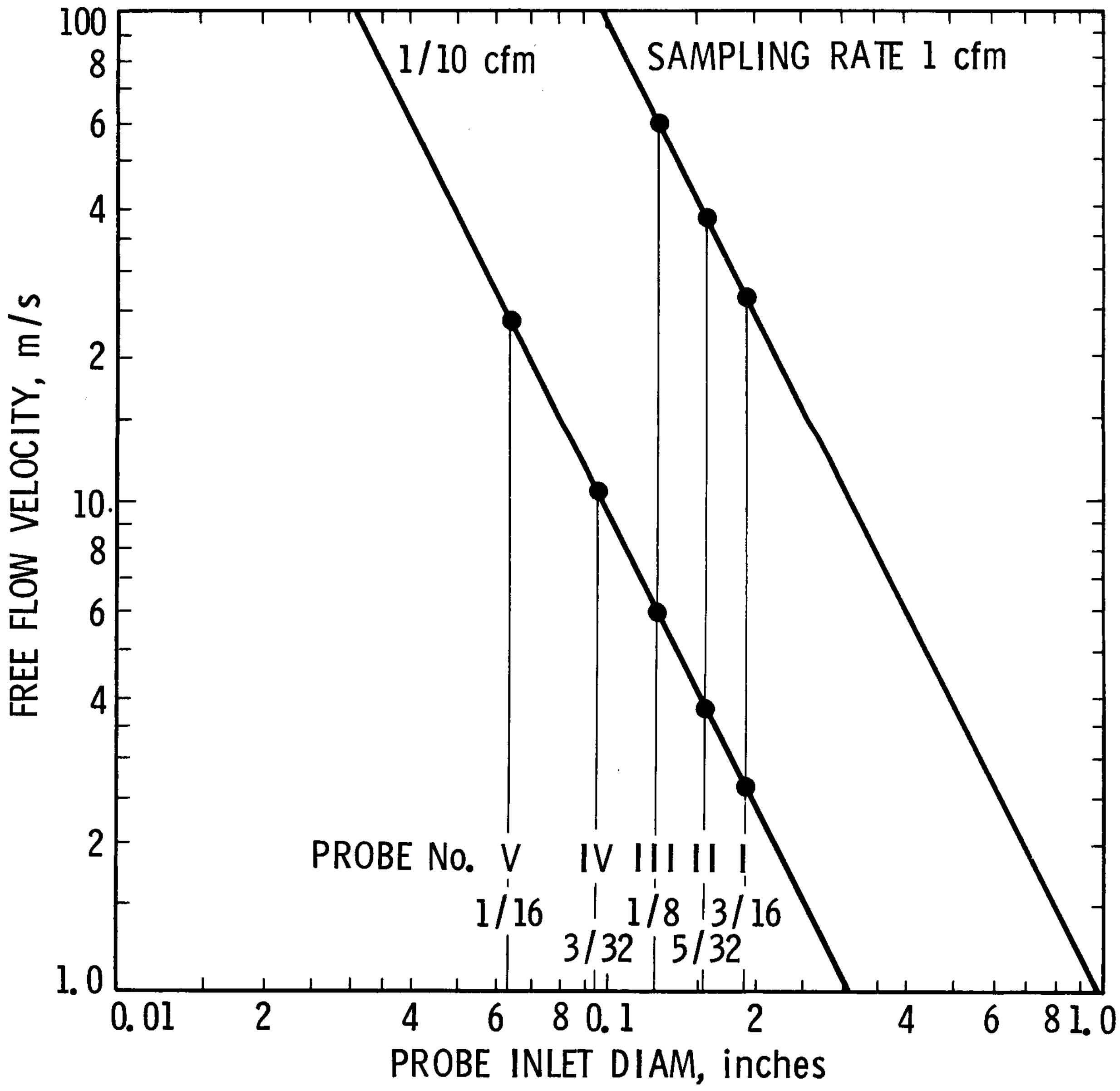

Figure 2. Isokinetic Probe Selection Chart

For Viking the discs were placed on the flapper valves of the payload diaphragm for transport, hoist, and as required on pad. For Voyager, the discs were placed on the flapper valves of the aft protective cover during transport and at the splitlines of the Voyager payload diaphragm during transport, hoist, and as required on pad. The discs were attached at the sampling location by using double-back tape.

After retrieval from the spacecraft, the discs were examined under a microscope and comparisons made against the previously determined background count. If appropriate, discs were sent to the chemical analysis lab for particle identification. This information was used to determine the particle source and to pinpoint possible contaminating mechanisms.

4.0 RESULTS

4.1 Visual Inspection Results

The encapsulation visual inspection for each Viking and Voyager spacecraft generally found no visible particles on the spacecraft surfaces. On Viking, one lander bioshield cap had a few black particles on it. On Voyager 1, the antenna and plume shields were dirty. In both instances, the hardware was cleaned and the subsequent visual inspection revealed that the spacecraft surfaces were acceptable.

For both Viking and Voyager, on-pad spacecraft problems required decapsulation of flight spacecraft. This provided opportunities to determine whether the indirect measurement methods, e.g., particle counters and disc samples, were providing a reasonable indication of what was occurring underneath the protective shroud. The indirect methods did provide early indications of problems for Viking which were confirmed by post decapsulation inspection. This will be discussed in more detail in the Launch Complex 41 air quality results. The decapsulation inspection of Voyager 1 showed that the spacecraft was visually clean. This result was consistent with the favorable results from the indirect measurements at the launch pad.

4.2 Clean Room Data

As noted in Table 1 Viking and Voyager hardware passed through several different clean rooms during the course of the Cape Canaveral operations. The principal clean rooms were in Hanger AO, ESA 60A, and SAEF's 1 and 2. These clean rooms were certified to meet Class 100,000 air cleanliness requirements prior to the arrival of flight hardware. Since these clean rooms were subjected to an extensive facility cleaning program preceding the certification, there was no difficulty in satisfying the requirements. Typical results from two of the clean rooms are shown in Table 4. This data was obtained by using light scattering particle counters.

TABLE 4 - CERTIFICATION DATA FROM SPACECRAFT ASSEMBLY AND ENCAPSULATION FACILITY CLEANROOMS

	No. Of Particles $> 0.5\mu$
Spacecraft Assembly and Encapsulation Facility #1	8 to 148
Spacecraft Assembly and Encapsulation Facility #2	1 to 75

4.3 Support and Launch Complex 41 Air Conditioning Systems Data

The air conditioning systems were environmentally certified by using a light scattering particle counter a few days prior to use, retested the day before use and again verified just prior to integration with flight hardware. The payload support air conditioning units which provided air to the encapsulated spacecraft in the Spacecraft Assembly and Encapsulation Facilities, in the airlock, and during transportation as well as the Launch Complex 41 systems consisting of the hoisting air conditioning (5th level), payload air conditioning (12th level) and Centaur Electronics Module air conditioning (11th level) were certified to meet or exceed the Federal Standard 209b for providing Class 100 air delivery. An example of this data is shown in Table 5.

At Launch Complex 41, the air quality of the inlet air for the payload was periodically monitored for Viking and continuously monitored for Voyager. Particle counts from the inlet air are shown in Table 6. This data was obtained using light scattering particle counters with isokinetic probes. The air cleanliness requirement for Class 100 air was satisfied at all times except when a High Efficiency Particulate Airfilter (HEPA) failed on Viking.

The exhaust air exiting from the bottom of the payload was qualitatively measured by disc samples during transport and hoist, and, if needed, at the top of the launch vehicle. The results from this data are given in Table 7. For Voyager 1, the microscopic examination of the pair of disc samples installed for the rollout, erection, and mating of the encapsulated payload to the launch vehicle showed particle counts significantly higher than the background count. Representative particles were subjected to a microchemical analysis. The results of this analysis are shown in Table 8. Subsequent sets of discs showed no indication of continued particulate shedding within the encapsulated payload.

TABLE 5 - PREMATE SURVEY DATA FOR ENCAPSULATED PAYLOAD AIR CONDITIONING SYSTEMS

	0.5μ	5.0μ
Payload Environmental Support Trailer	0-67	0
Launch Complex 41 Level 5	5-40	0
Level 11	0-2	0

TABLE 6 - ON-PAD PARTICLE MONITORING RESULTS TO PAYLOAD SHROUD

Range of Number of Particles Greater Than or Equal To 0.5 or 5μ Size Particle Diameter

	Particle Diameter	Requirement	Viking	Voyager
Inlet Air	0.5μ	≤100	5 to 50*	5 to 15
	5.0μ	0	0*	0
Exhaust Air	0.5μ	≤1000	5 to 230	20 to 180
	5.0μ	7	0 to 3	0 to 3**

* Except when HEPA filter failed.

** One reading, one day of 8.

TABLE 7 - SUMMARY OF VIKING AND VOYAGER DISC SAMPLING RESULTS

Number of Occurrences of Excessive Contamination

	Viking	Voyager
Post Encapsulation In Assembly Facility	0	0
Transport and Hoist	0	0
On-Pad	0	1

TABLE 8 - ANALYSIS RESULTS OF PARTICLES OBTAINED FROM VOYAGER DISC SAMPLES

Particle No.	Analysis Identification	Probable Source
1	Iron oxide, a steel corrosion product.	Common contaminants from facilities found in soils and atmosphere at Cape Canaveral.
2	A Latex paint particle.	
3	A zinc rich paint particle.	
4 and 5	Aggregates of aluminum corrosion products, coquira and sand.	Common contaminants from soil and atmosphere.
6	Coquina (Limestone)	Soil and atmosphere.
7	Aluminum alloy.	Disc sample.

Quantitative samples of the exhaust air were obtained periodically after installation of the payload on the launch vehicle. The Viking data is given in Figure 3, The following discussion provides two examples of how this type of data can be used to obtain an early indication of a problem in the air conditioning system or in the payload cavity. As the data shown in Figure 3 was being obtained during the Viking Program, the upward increase in particle contamination exhausting from the payload shroud was noted. Subsequent trouble shooting pinpointed the problem as a HEPA filter failure. The filter was taken "off-line". Because of an unrelated spacecraft problem the payload was decapsulated. Visible contaminants, most likely from the filter, were found on the spacecraft. Subsequent to the temporary repairs made to the air conditioning system, but prior to the decapsulation, another increase in exhaust air contamination was observed. Concerns were expressed as to the origin of the contamination, and it was speculated that something on the spacecraft or shroud had ruptured. Inspection of the internal structure of the shroud after decapsulation showed that the insulation matting was torn in several places. Speculated cause of the problem was the GN_2 purge (5#/minute) which entered the shroud impinging on the insulation matting at sonic speed for approximately 102 hours. The exhaust data in both of these instances proved to be useful to the launch team. During subsequent operations for both Viking and Voyager there were no recurrences of exhaust air quality exceeding the acceptance criteria.

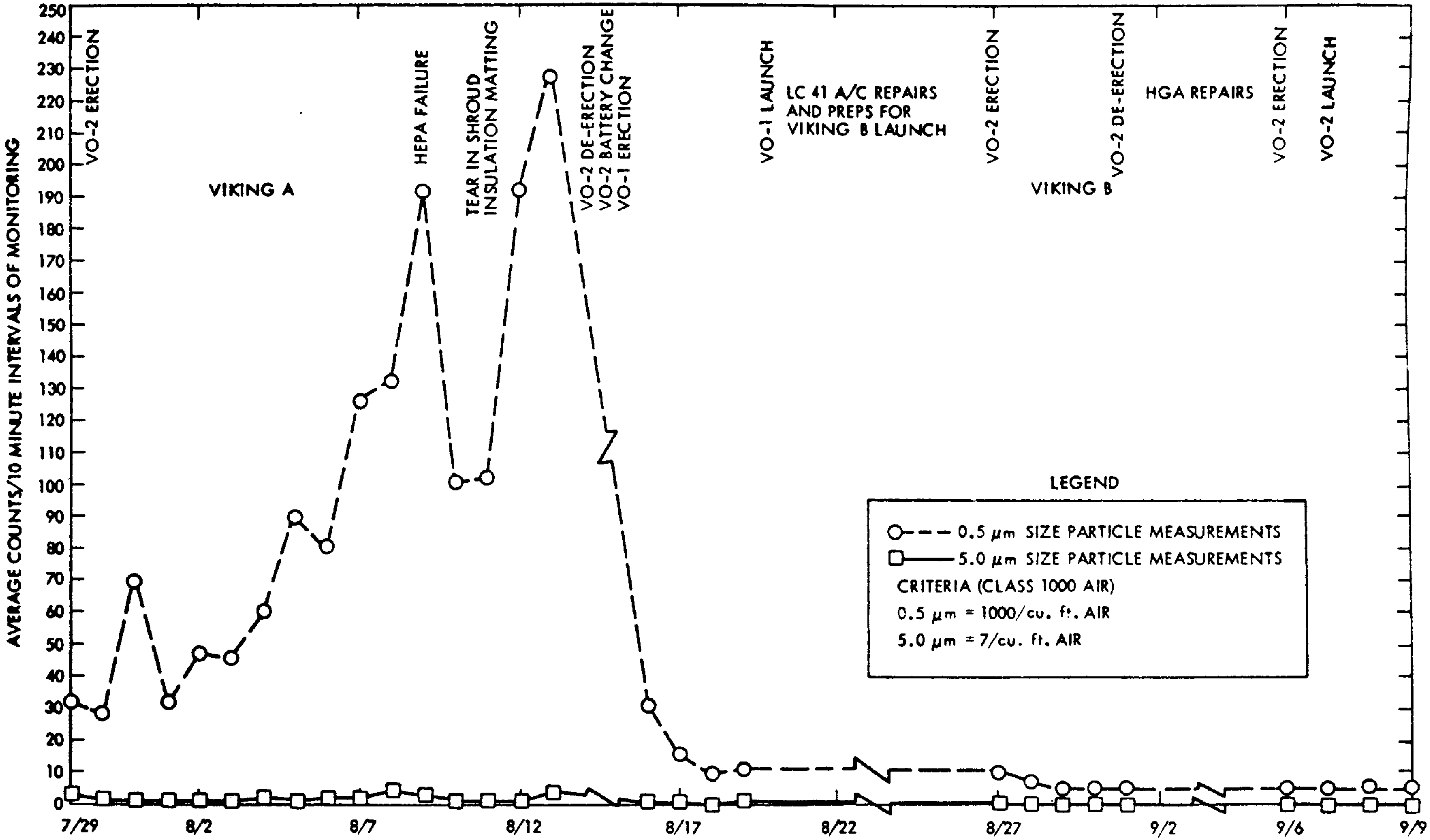

Figure 3. Particle Measurements of Viking Payload Exhaust Air at Launch Complex 41

5.0 IN-FLIGHT EXPERIENCE

Since the Viking and Voyager spacecraft were three axis stabilized, celestial sensors are used for guidance (Figures 4 and 5). If a particle comes into the star tracker's field of view, the intensity measurements increase. By determining the number of times "blips" occur, a relative measure of the number of particles passing through the field of view can be determined. Such a relative measure serves as a "report card" of the success of the particulate contamination control program. The bright particle occurrences for Viking and Voyager are shown in Figures 6, 7, 8. Release of particles were generally related to dynamic events on board the spacecraft such as the firing of pyrotechnic devices and the slewing of the science platform. Also, it should be noted that bright particle occurrences decrease as a function of time. This results from three factors: 1) particles released once generally do not re-attach and re-release, 2) the size of sensible particles increases as the spacecraft travels away from the sun, (e.g., 8μ diameter particle required near Earth, 15μ diameter near Mars, 3) no spacecraft material degradation generating particles is occurring. The conclusion to be drawn from these results is that there were relatively few bright particle occurrences and that the contamination control program for Viking and Voyager was very good. No science instrument has attributed any degradation in performance to particulate contamination. This again attests to the adequacy of the Viking and Voyager contamination control programs.

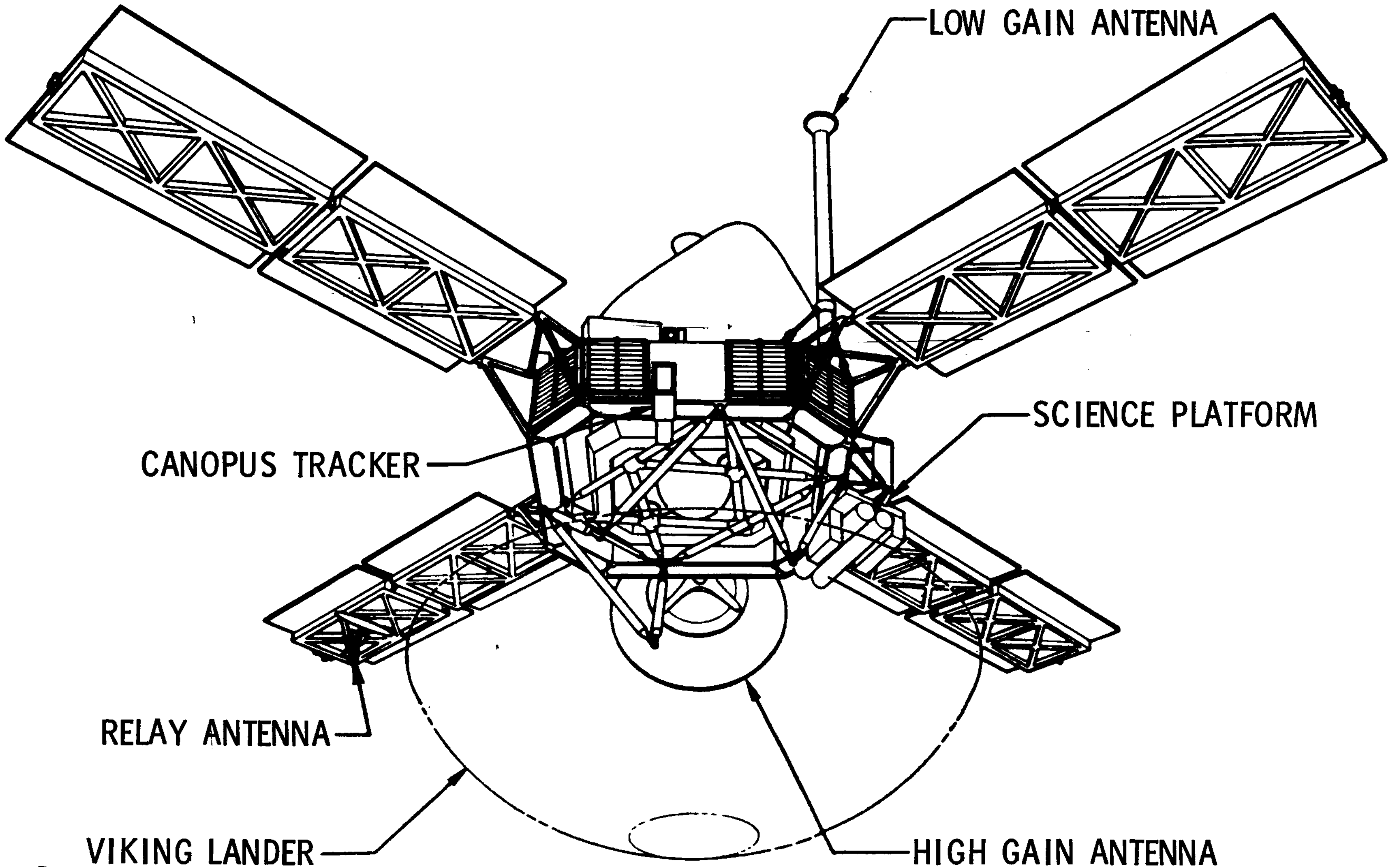

Figure 4. Viking Spacecraft

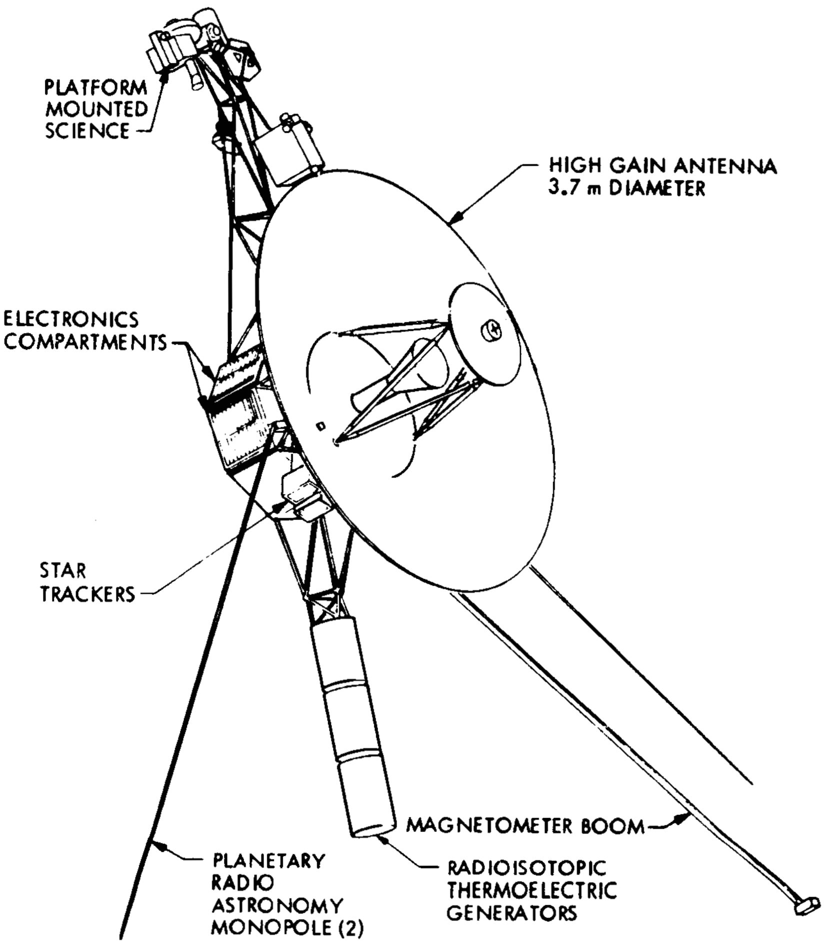

Figure 5. Voyager Spacecraft

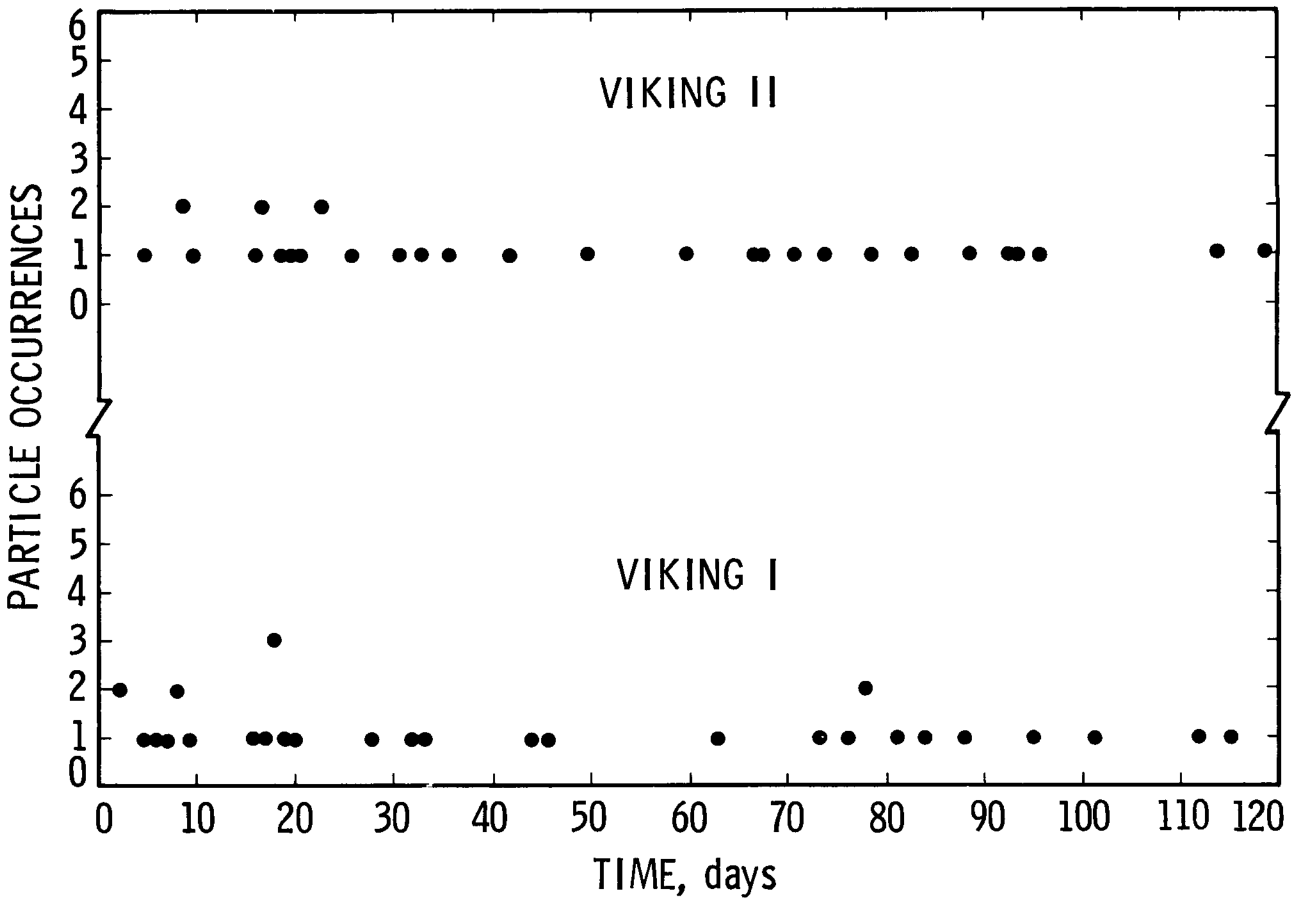

Figure 6. Viking In-Flight Particle Occurrences, Launch Through Four Months

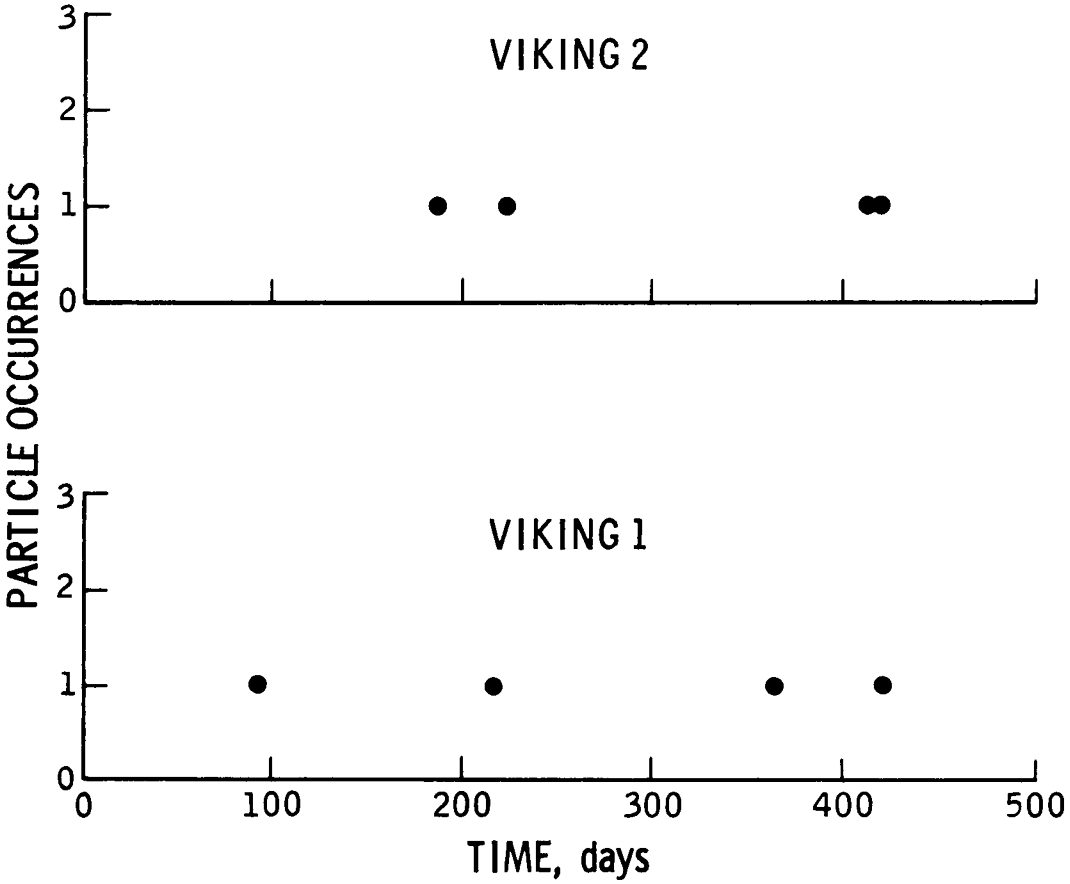

Figure 7. Viking Extended Mission In-Flight Particle Occurrences

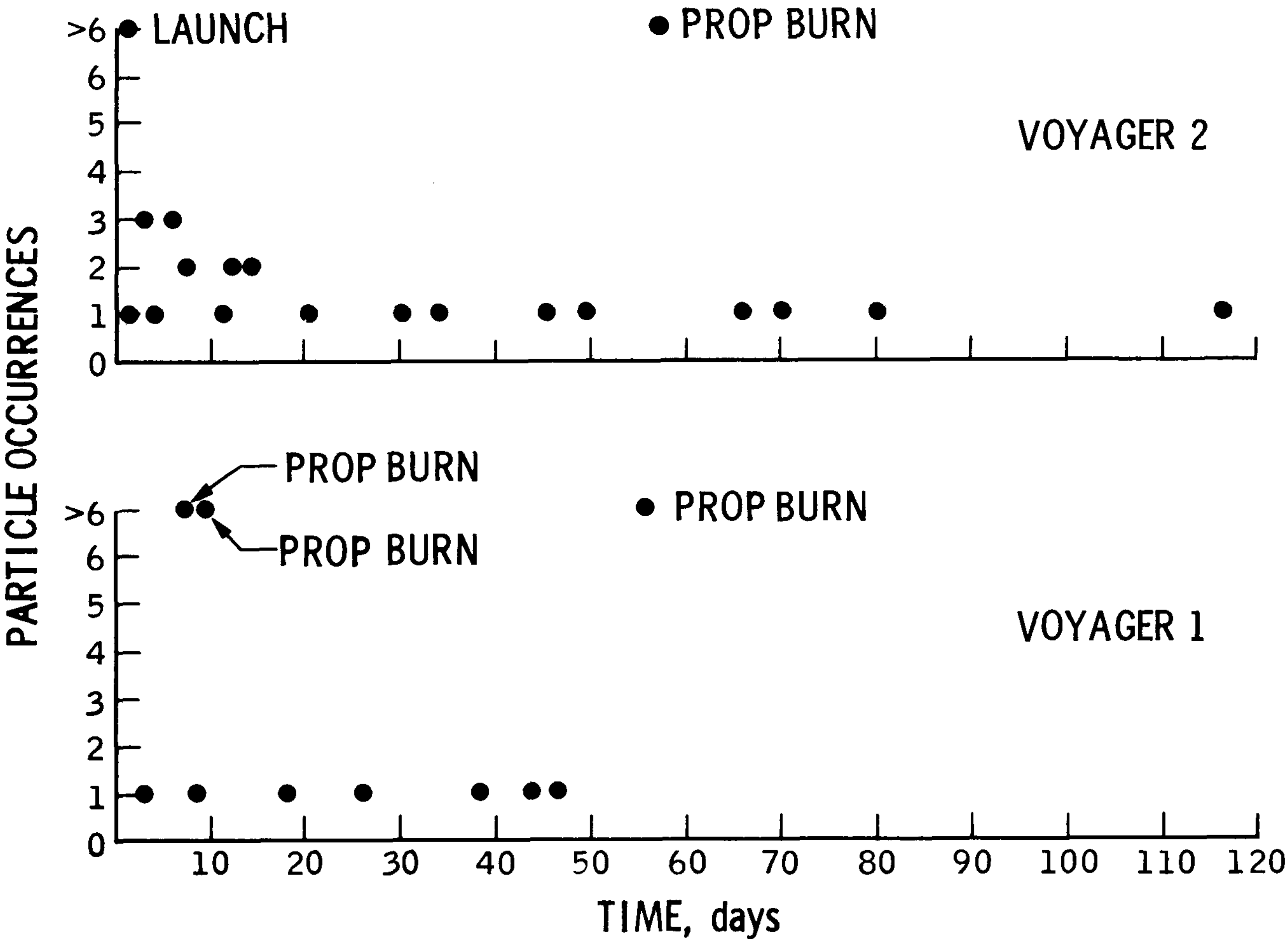

Figure 8. Voyager In-Flight Particle Occurrences, Launch Through Four Months

6.0 CONCLUSIONS

The particulate contamination control program implemented on the Viking and Voyager spacecraft resulted in visually clean spacecraft at encapsulation/launch and no in-flight anomalies attributable to particles

The particulate monitoring methods utilized provided useful quantitative and qualitative data for assessing the adequacy of the air delivered to the spacecraft. Monitoring both the inlet and exhaust air after encapsulation provides enhanced assurance that the spacecraft remains in a clean condition during transport and on-pad operations. Disc samples are a useful tool for collecting particulates for qualitative evaluation when it is appropriate to identify the source of the particles.

Acknowledgements

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References

1. Schneider, H. "Evaluation of Particulate Contamination for Unmanned Spacecraft Prelaunch Operations", the Journal of Environmental Sciences, January/February 1975